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Use of fan shell waste as fine aggregate in concrete subjected to coastal erosion

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Abstract*– The present study is based on the use of crushed fan shell waste (FSW) between the sizes of 0.6 mm and 2.36 mm incorporated in the concrete mix to measure its properties in the fresh and hardened state. This waste product is of great interest for the construction sector, as an additive or as a partial or total replacement of aggregates in the production of concrete or as a soil amendment. The experimental design consists of the preparation of two concrete mixes designed for strengths of f'c=175 kg/cm^2 (M1) and f'c=210 kg/cm^2 (M2) and water/cement ratios of 0.61 and 0.55, respectively. The mixes were supplemented with 5, 10, and 15% crushed FSW to replace the fine aggregate, and the mix was evaluated for workability in fresh concrete, compressive strength, and indirect tensile strength in hardened concrete after 14 and 28 days of curing. Flowability and consistency were slightly affected, as were plasticity and workability for M1 and M2, respectively. The design compressive strength was exceeded by both experimental specimens (M1 and M2), reaching 196.99 and 234.86 kg/cm^2, respectively. Indirect tensile strength showed a slight decrease as the amount of FSW was increased, reaching up to 20.09 kg/cm^2 for M2. Finally, the results showed that the replacement at 5% guaranteed a higher compressive strength of the concrete at 28 days, although at 10 and 15% also exceeded the design strength.

***Keywords--* Seashell residues, Mechanical properties, Substitution, concrete.**

INTRODUCTION

It is a fact that the growing construction industry alarmingly contributes to the depletion of natural resources and the emission of toxic substances into the atmosphere due to cement manufacturing [1, 2]. On the other hand, coastal erosion is a phenomenon that significantly affects concrete structures, deteriorating them and reducing their lifespan. This wear and tear on constructions represents not only an economic problem but also an ecological one, as more materials and resources are required to repair or replace these damaged structures. Despite these challenges, efforts continue to test alternative materials, of natural or industrial origin, that mitigate the possible damage caused to structures. The use of marine shell waste (RCM), in its different species [1-6], as fine aggregate, coarse aggregate, and even as a replacement for cement, are viable alternatives due to their high calcium carbonate content [7, 8]. This compound, when burned at high temperatures, produces calcium oxide [8], an essential component in cement manufacturing. The incorporation of RCM not only has the potential to improve the durability of constructions but also to reduce the dependence on natural resources, promoting more sustainable practices.

One of these mollusks is the so-called scallop (*Argopecten purpuratus*), an important marine species in Peru, primarily cultivated for export [9]. In the province of Sechura, in northern Peru, 80% of the national production is concentrated [10], generating hard shell waste that has been deposited in municipal and clandestine landfills. These hard residues accumulate in open spaces, becoming a significant source of environmental pollution due to the emission of unpleasant odors, the proliferation of insects, and other microorganisms. This study uses crushed scallop shells as a partial substitute for fine aggregate with the aim of reducing the demand for quarry material and decreasing the storage of shell waste in landfills. Their use does not cause adverse effects on the density and strength of concrete below 20% [11]. On the contrary, the angular shape of the shell particles can contribute to better compaction [6]. It is evident that there is an urgent need for alternative solutions in the field of civil engineering that allow for the environmentally friendly reuse of these residues and help curb the continuous depletion of natural resources.

Therefore, it is essential to explore new alternatives that not only mitigate this problem but also make use of waste materials. By employing these residues in the construction industry, we can move towards a circular economy, where waste materials are reintegrated into the production cycle, minimizing environmental impact. Research and development in this field are crucial to finding solutions that are not only technically feasible but also beneficial for the environment and society as a whole.

Various studies have investigated the use of marine waste in construction, highlighting their potential benefits in terms of durability and sustainability. One of the earliest studies focused on the use of crushed oyster shells as a partial replacement for sand, yielding positive results in several aspects. These include freeze-thaw processes, carbonation, chemical attack resistance, and improved permeability resistance [12]. Additionally, [13] found that although the workability of the material is affected as the replacement rate of shells increases, this issue can be mitigated through the use of specific additives. This suggests that initial challenges can be overcome with appropriate adjustments in the material composition, reinforcing the potential of marine waste in the construction industry.

Similarly, laboratory tests conducted by [2] confirm the feasibility of valorizing this waste as a substitute in the composition of permeable concrete to improve its durability. These findings are significant as they suggest a dual advantage: on one hand, the need for sand extraction is reduced, and on the other, waste that would otherwise be discarded is utilized, thus contributing to environmental sustainability. Other studies have focused on evaluating the performance of cementitious materials through the partial and total replacement of fine and coarse aggregates [1, 3, 14, 15, 16], providing important findings in this field. Their research highlights the potential use of oyster shell waste to improve various physical and mechanical properties. In particular, an improvement in both static and dynamic mechanical properties has been observed, further reinforcing the argument for incorporating these residues into construction.

Finally, current research provides additional evidence of the potential of marine waste, specifically crushed scallop shells, as sustainable materials for construction. The observed benefits in terms of durability and strength indicate that these residues can play a crucial role in the development of more sustainable and efficient construction materials.

MATERIALS AND METHODS

A. *Materials*

The research follows a quasi-experimental design with increasing stimulus and post-test only. The materials used were: Type I Portland cement, fine and coarse aggregate, potable water, and crushed scallop shells (CSS). The fine aggregate was replaced with RCA to reduce the need for quarry-extracted materials and decrease the accumulation of shell waste. The CSS was collected from a local Aquaculture and Fishing company, underwent a rigorous cleaning process to remove saline and infectious substances, and was manually dried at room temperature. Subsequently, the CSS was crushed to a length of approximately 0.6 to 2.36 mm.

B. *Physicochemical characterization of materials*

To analyze the chemical composition of the fan shell waste (RCA), the test method by spectrophotometer and atomic absorption of iron and aluminum was used, the results of which are shown in Table I. The RCA particles exhibited a rough surface, angular and irregular edges, and varying dimensions.

TABLE I
CHEMICAL COMPOSITION OF FAN SHELL WASTE

	Determination	Result [%]
SiO_2	Silicon Oxide	85.19
Al_2O_3	Aluminum Oxide	0.67
Fe_2O_3	Iron Oxide	0.52
CaO	Calcium Oxide	1.28
MgO	Magnesium Oxide	0.36
NaO	Sodium Oxide	0.23
K_2O	Potassium Oxide	2.34
TiO_2	Titanium Oxide	0.02

The granulometric analysis of the RCA, fine and coarse aggregate indicated that these materials did comply with what is specified by the Peruvian Technical Standard NTP 400.012 and ASTM C33, as observed in Fig. 1, Fig. 2 and Fig. 3.

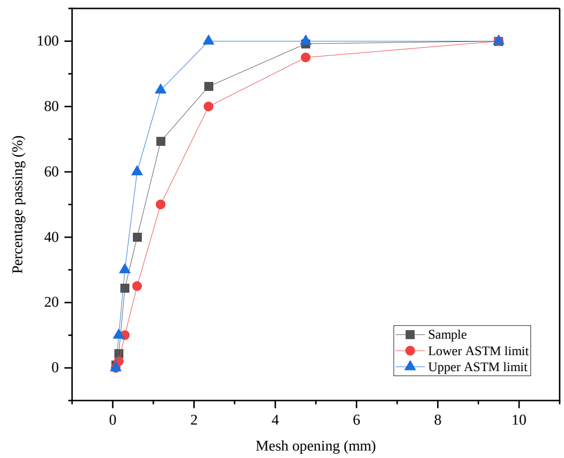

Fig. 1 Granulometric curve of the RCA. Limits according to ASTM C33.

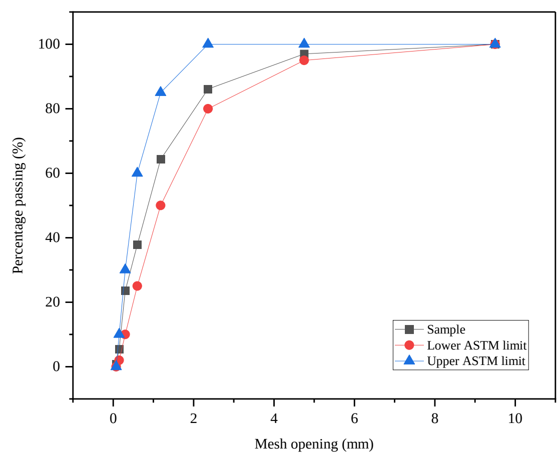

Fig. 2 Granulometric curve of the fine aggregate. Limits according to ASTM C33.

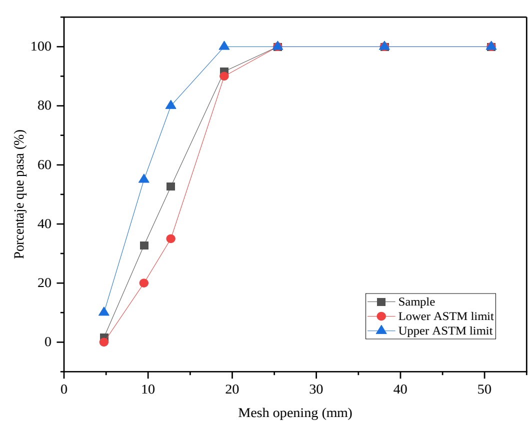

Fig. 3 Granulometric curve of the coarse aggregate. Limits according to ASTM C33.

C. *Mix design*

The mix design followed the ACI 211.1 committee guidelines [17] and the considerations of the Peruvian technical building standard E.060 for Reinforced Concrete [18]. A design slump of 3 to 4 inches was established, according to NTP 339.045, with water-cement ratios of 0.61 and 0.55 respectively, and a maximum nominal size of coarse aggregate of ½ inch. The material proportions are shown in Table II.

TABLE II
SIMPLE CONCRETE MIX DESIGN FOR 175 AND 210 KG/CM^2

	175 (kg/cm^2)			210 (kg/cm^2)		
	w/c Ratio (0.61)			w/c Ratio (0.55)		
Material	**Proportion**	**Weight (kg)**	**Mix (%)**	**Proportion**	**Weight (kg)**	**Mix (%)**
Cement	1.00	343.95	16.54	1.00	387.10	18.53
Fine aggregate	1.82	626.72	30.13	1.53	593.23	28.04
Coarse aggregate	2.53	871.83	41.92	2.25	871.83	41.74
Water	0.69	237.42	11.41	0.61	236.76	11.33
Total for 1 m^3		2079.92	100.00		2088.92	100.00

D. Test scheme

Workability tests were conducted for each of the fresh mixes according to NTP 339.035 [19] and ASTM C143 standards [20]. A total of 72 specimens measuring 15x30 cm were used: 36 designed for 175 kg/cm² and another 36 for 210 kg/cm². Of these, 24 were used to measure compressive strength according to NTP 339.034 [21], and 12 to measure indirect tensile strength using the "Brazilian Method" [22]. The tests were conducted at 14 and 28 days of curing, with partial replacements of fine aggregate by crushed scallop shells in proportions of 5%, 10%, and 15%.

The four types of mixes designed were: plain concrete (CS), CS with 5% RCA (CS3RCA), CS with 10% RCA (CS4RCA), and CS with 15% RCA (CS5RCA). A water-cement ratio of 0.61 and 0.55 was used to counteract the high absorption of the RCA and ensure proper hydration of the cement, thus forming a strong paste.

The results of the tests carried out were processed using the statistical technique analysis of variance (ANOVA) to determine the differences between the groups. Then, the Tukey test for multiple comparisons was used to identify pairs of groups that are significantly different from each other, at a significance level of 5%.

RESULTS AND DISCUSSION

A. Settlement of Fresh Concrete

The results of the tests on the concrete in its fresh state are shown in Table III.

TABLE III
SETTLEMENT OF THE CONCRETE IN ITS FRESH STATE

Mixes	w/c Ratio 175 (kg/cm^2)	Settlement (inches)	Variation (%)	w/c Ratio 210 (kg/cm^2)	Settlement (inches)	Variation (%)
CS	0.61	3.50	0.0	0.55	3.63	0.0
CS5RCA	0.61	3.60	2.90	0.55	3.81	5.0
CS10RCA	0.61	3.71	6.00	0.55	4.17	14.9
CS15RCA	0.61	3.82	9.14	0.55	4.25	17.1

The settlement of the concrete in its fresh state for a mix design of 175 kg/cm² remained within the expected ranges (3 to 4 inches) for all RCA proportions, not affecting its fluidity and consistency despite having a water/cement ratio of 0.61, as seen in Table 3. Regarding the mix design of 210 kg/cm², the settlement exceeded 3 inches in the CS10RCA and CS15RCA mixes, which slightly lost plasticity and workability with a water/cement ratio of 0.55, but remained within the range of 3 to 4 inches.

B. Compressive strength

The results of the compression strength tests on hardened concrete are shown in Fig. 4, Fig. 5, Fig. 6, Fig. 7, Fig. 8 and Fig. 9 for specimens of 150 mm x 300 mm.

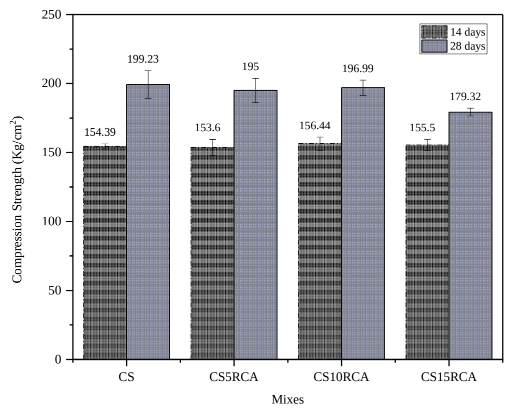

Fig. 4 Compression strength of concrete specimens in hardened state at 175 kg/cm^2.

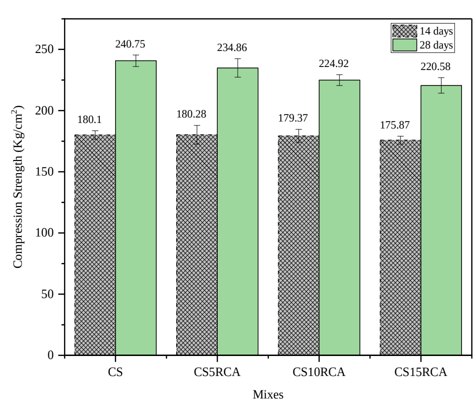

Fig. 5 Compression strength of concrete specimens in hardened state at 210 kg/cm^2.

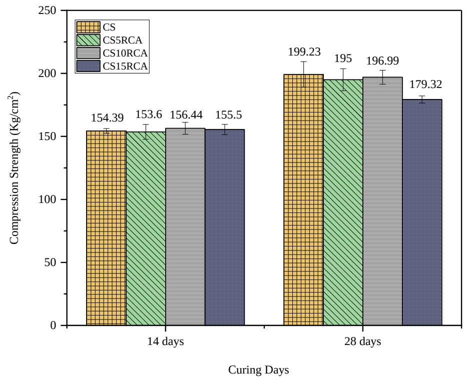

Fig. 6 Effect of RCA replacement on the compression strength of 175 kg/cm^2 concrete.

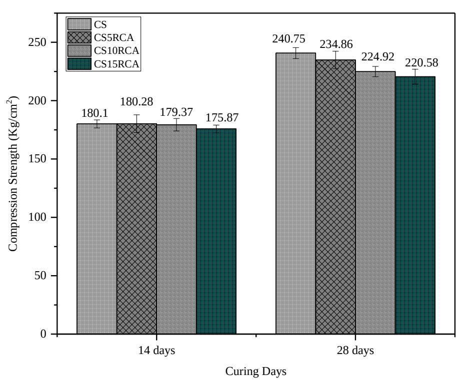

Fig. 7 Effect of RCA replacement on the compression strength of 210 kg/cm^2 concrete.

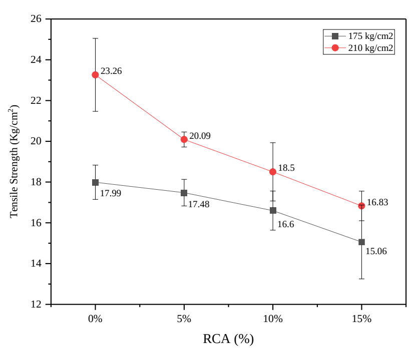

Fig. 8 Effect of RCA replacement on the tensile/ strength at 28 days.

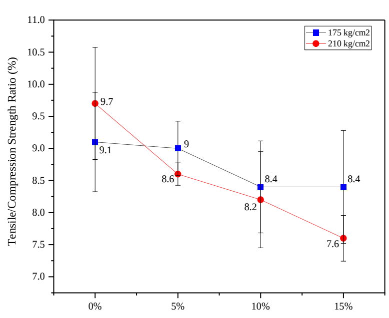

Fig. 9 Effect of RCA replacement on the tensile compression strength ratio at failure at 28 days.

This mechanical property, expressed in Fig. 6 and Fig. 7, shows that the concrete mixes exceeded the design strength at 28 days of curing, either for 175 kg/cm² and 210 kg/cm², being a little more than 13% and 14% respectively; a similar situation was achieved by [23] using calcareous residues of fan shells in replacement of cement at 5, 10, and 15%. Also, [12] came to test that when the use of crushed oysters increases, the resistance tends to decrease in the long term, so it is advised to use said material no more than 10%. For their part, [24] achieved resistances according to programmed designs by using residues of oyster shells combined with fly ash, in proportions of up to 20%. On the other hand, [6] affirm that the maximum level of replacement is variable, but they recommend that an optimal replacement would be 5% and a maximum of 40% in a range of RCA particles from 1.19 to 4.75 mm.

Fig. 6 and Fig. 7 show the evolution of the compressive strength of concrete at different levels of RCA replacement. These results demonstrate that there is no clear and sustained reduction in the compressive strength of the concrete compared to conventional concrete (CS) when the RCA replacement is increased, although there is an average increase above the design strengths (175 and 210 kg/cm²); this could be due to the proportion of RCA used and the diameter of its particles [7], reaching its maximum strength (196.99 kg/cm²) with 10% RCA for 175 kg/cm² and (234.86 kg/cm²) with 5% RCA for a design of 210 kg/cm² [6], both at an age of 28 days. This result is similar to that of [24] and [25]. In addition, the presence of RCA particles, up to 2.36 mm, thicker and more angular, would favor the interlocking of particles and thus decrease the capillary pores that would impair their resistance [6].

C. Indirect tensile strength

The indirect tensile strength was evaluated both as a resistance of the concrete and as a ratio of compressive strength. Fig. 9 shows the tensile strength due to the rupture of the concrete at 28 days of age. This is slightly affected when the proportion of RCA is increased, similar to that observed by [6] and [12] at 28 days. In this case, it seems that the RCA particles are not directly affecting the resistance of the matrix and, on the contrary, they fulfill their function of adherence to the cement paste as natural aggregates do.

When evaluating the tension/compression resistance ratio (Fig. 9), the behavior presents similar characteristics. The variations are small between both mix designs and are between 7 and 9%. These results confirm that the compressive strength of the concrete is consistent with those that come from the tensile test, which would indicate that there is good adherence between the RCA particles and the cement paste.

Tensile strength can be predicted using compressive strength through linear regression analysis. In this case, an approximation to the required model was made since we only used data from both strengths at 28 days of curing (Fig. 10). Depending on the amount of data available, whether from strengths and various curing days, the accuracy and validity of the model can be ensured.

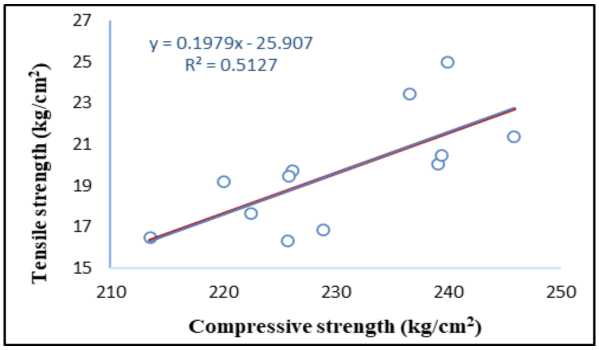

Fig. 10 Relationship between the tensile and compressive strength of concrete with RCA.

D. *Statistical analysis*

All compressive and tensile strength data, according to the age of the concrete specimens, showed a normal distribution ($p>0.05$); therefore, an analysis of variance and the Tukey multiple comparison test were performed, with the results shown in Tables IV, Table V, Table VI and Table VII.

TABLE IV
ANALYSIS OF VARIANCE (ANOVA) FOR COMPRESSIVE STRENGTHS ACCORDING TO THE AGE OF THE CONCRETE SPECIMENS.

f'c	**Age of specimens (days)**	**Average (kg/cm^2)**	**Standard Deviation**	**F**	**Significance (p)***
175 kg/cm^2	14	154.98	3.93	0.238	0.868
	28	192.63	10.31	4.525	0.039
210 kg/cm^2	14	178.91	4.83	0.468	0.713
	28	230.28	9.72	7.291	0.011

* The difference in means is significant at the 0.05 level ($p<0.05$)

As for the effect of the RCA percentage, it can be observed in Table V that there are only significant differences ($p<0.05$) in the concrete specimens at 28 days of curing. In Table 6, it is noted that there are significant differences ($p<0.05$) between the resistances of the standard CS sample and CS15RCA for 175 kg/cm^2, in addition to CS with CS10RCA and CS15RCA for 210 kg/cm^2.

TABLE V
MULTIPLE COMPARISON AMONG THE SAMPLES OF CONCRETE SPECIMENS ACCORDING TO AGE, FOR COMPRESSIVE STRENGTH.

Samples	**CS**	**CS5RCA**	**CS10RCA**	**CS15RCA**
175 kg/cm^2 at 28 days of curing				
CS	-----	0.893	0.981	0.043*
CS5RCA		-----	0.988	0.116
CS10RCA			-----	0.073
CS15RCA				-----
210 kg/cm^2 at 28 days of curing				
CS	-----	0.631	0.044*	0.013*
CS5RCA		-----	0.243	0.070
CS10RCA			-----	0.804
CS15RCA				-----

* The difference in means is significant at the 0.05 level ($p<0.05$)

TABLE VI
ANALYSIS OF VARIANCE (ANOVA) FOR INDIRECT TENSILE STRENGTHS

	Age of specimens (days)	**Average (kg/cm^2)**	**Standard Deviation**	**F**	**Significance (p)***
175 kg/cm^2	28	16.78	1.52	3.726	0.061
210 kg/cm^2	28	19.67	2.69	15.222	0.001

* The difference in means is significant at the 0.05 level ($p<0.05$)

In Table VI, it can be seen that there are only very significant differences ($p<0.01$) in the concrete specimens of 210 kg/cm^2. In Table VII, it is noted that there are significant differences ($p<0.05$) between the resistances of the standard CS sample with CS10RCA and CS15RCA, as well as between CS5RCA and CS15RCA.

TABLE VII
MULTIPLE COMPARISON AMONG THE CONCRETE SPECIMEN SAMPLES, FOR INDIRECT TENSILE STRENGTH.

Samples	**CS**	**CS5RCA**	**CS10RCA**	**CS15RCA**
210 kg/cm^2 at 28 days of curing				
CS	-----	0.050	0.006**	0.001**
CS5RCA		-----	0.432	0.045*
CS10RCA			-----	0.338
CS15RCA				-----

* The difference in means is significant at the 0.05 level ($p<0.05$)
** The difference in means is very significant at the 0.01 level ($p<0.01$).

Regarding the effect of RCA on the compressive strength of concrete, it was determined that there are significant differences ($p<0.05$) only between the resistances of the samples at 28 days of curing. Statistically, it reaffirms what was said earlier that the components and curing time help in the consolidation of this mechanical property, as there are no signs to say otherwise. The multiple comparison determined that at 28 days of curing, the experimental samples with 5% RCA are the ones that show better behavior compared to CS, although the samples with 10 and 15% RCA also managed to exceed the design resistance, at the age of 28 days. Consequently, it is evident that the presence of RCA as a functional component of concrete positively influences its compressive strength.

CONCLUSIONS

- Proper cleaning of RCA is essential to ensure its chemical composition and to guarantee an effective replacement of fine aggregates in the concrete mix. This not only improves the quality of the concrete but also contributes to sustainability by reusing recycled materials.

- The incorporation of RCA does not significantly affect the fluidity and consistency of 175 kg/cm² concrete. However, in 210 kg/cm² concrete, there is a slight loss of plasticity and workability due to the water/cement ratio. Despite this, both properties remain within acceptable ranges, indicating that RCA can be used without compromising the quality of the concrete.
- A 5% replacement level of RCA significantly improves the compressive strength of the concrete at 28 days. Even replacement levels of 10% and 15% exceed the design strength, demonstrating that RCA can be a viable and effective alternative to improve the mechanical properties of concrete.
- Although the strengths of concrete with RCA are above the design, there is no clear and sustained reduction compared to conventional concrete (CS). This suggests that the use of RCA does not compromise the structural integrity of the concrete and can be considered a viable option for structural applications.
- As a result of this research, further studies have been proposed to analyze concrete under various environmental conditions. Additionally, reinforced concrete studies must be carried out to evaluate its behavior and the potential effects on the embedded steel.

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